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Technical Report
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Abstract

Military training on fields and ranges at Canadian Forces Bases (CFB) is essential to prepare our troops for potential wars and/or peace missions. On the other hand, the growing concern of DND leaders and of the general population makes it necessary to evaluate the impacts of training on the environment. During the last 10 years, new methods of characterization have been developed to assess the energetic materials contamination, which is different from the usual contamination in residential or industrial scenarios. Recently, the efforts were focused on firing positions. Soil and biomass sampled at firing positions have shown detectable levels of gun propellant residues, such as 2,4-dinitrotoluene (2,4-DNT) and nitroglycerine (NG). In this study, aluminium witness plates were placed in front of the muzzle of the gun to collect residues propelled in the environment. Cotton wipes were used to collect the residues on plates. Moreover, as complementary data, soil samples were taken before and after the military exercise using a composite approach to be statistically representative. The energetic materials were analyzed at DRDC Valcartier in Quebec City by high performance liquid chromatography (HPLC) and metal analyses were performed at Bodycote Testing Group in Montreal only for soil samples. This work was realized in May 2005 and was supported by the Sustain Thrust of DRDC and the Strategic Environmental Research and Development Program (SERDP), Washington D.C., USA.

Résumé

L'entraînement militaire des Forces canadiennes est essentiel pour préparer les troupes aux guerres potentielles et/ou aux missions de paix. Par ailleurs, l'intérêt grandissant du MDN et de la population pour l'environnement rend nécessaire l'évaluation de l'impact de l'entraînement sur l'environnement. Au cours des 10 dernières années, de nouvelles méthodes de caractérisation on été développées pour évaluer la contamination en matériaux énergétiques qui est différente des scénarios résidentiel ou industriel habituels. Récemment, les efforts ont été concentrés sur les positions de tir. Des échantillons de sol et de biomasse prélevés aux positions de tir ont montré des quantités significatives de composés, tels que le 2,4-dinitrotoluène (DNT) et la nitroglycérine, appartenant aux compositions de poudres à canon. Dans cette étude, des plaques témoins en aluminium ont été placées en face de la bouche du canon pour récolter les résidus de tirs propulsés dans l'environnement. Les plaques ont été nettoyées à l'aide de compresses en coton afin de récupérer les résidus. De plus, des échantillons de sol ont été prélevés avant et après les exercices de tir comme données complémentaires selon une approche composite pour être statistiquement représentatifs. Les analyses des matériaux énergétiques ont été réalisées à RDDC Valcartier dans la ville de Québec, tandis que celles des métaux ont été effectuées chez Bodycote essais de matériaux à Montréal. Ce travail a été réalisé au mois de mai 2005 dans le cadre du vecteur "maintien en puissance" de RDDC et du programme américain de subvention «Strategic Environmental Research and Development Program (SERDP)», géré à Washington D.C., aux États-Unis.

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Executive Summary

The international context of demilitarization, the closure of military bases and the more stringent aspects of environmental laws have led to the establishment of new areas for research and development. Many activities of the Canadian Forces such as the firing of munitions, demolition, and the destruction of obsolete ammunition by open burning and open detonation may lead to the dispersion of energetic compounds and other munitions-related contaminants in the environment. Within this context, Defence Research and Development Canada -Valcartier (DRDC Valcartier), the US Army Engineer Research and Development Center (ERDC) and the Cold Regions Research and Engineering Laboratory (CRREL) initiated research programs to study the environmental impact of energetic materials that are found in the Department of National Defence (DND) and in the US Department of Defence (DoD) ammunition stockpiles. The programs on site characterization allowed the development of a unique expertise and positioned our departments to better understand the impacts of live fire training and to be in a readiness state to answer any inquiries and take corrective actions if needed. Training areas on Canadian Forces Bases (CFB), such as CFB Chilliwack, Shilo, Valcartier, Wainwright and Gagetown were characterized within the Canadian Program, sponsored by Director Land Environment (DLE) and by a major US DoD funding program, the Strategic Environmental R&D Program (SERDP). Recently, efforts were focused on firing positions. Soil and biomass sampled at firing positions showed detectable levels of gun propellant residues, such as 2,4-dinitrotoluene (2,4-DNT) and nitroglycerin (NG). A preliminary study performed in the past showed that firings propel in the environment considerable amounts of residues in front the muzzle of the gun.

This report describes the study of residues collected in front of the muzzle of two kinds of guns, the Mark II and C3 105-mm howitzers, during an artillery exercise performed from May 9 to May 12, 2005 at CFB Gagetown in New-Brunswick. Aluminium witness plates were placed in front of the gun and residues were collected on them with cotton wipes after firings. Moreover, complementary data were obtained in collecting soil samples in front of the gun before and after firings. Soil samples taken before the artillery exercise made it possible to evaluate contamination present in the soil before the military training started. Samples (soils and cotton wipes) were analyzed for explosive contamination using the High Performance Liquid Chromatography (HPLC) at DRDC Valcartier. Metal concentrations were measured only in soil samples by inductively coupled plasma/mass spectrometry (ICP/MS) at an external laboratory (Bodycote Testing Group, Montreal, Quebec). In this work, the influence of the quantity of gun propellant used per firing, the type of gun and the number of firings done by a specific gun on the amount of collected residues in front of the gun will be evaluated. This type of study is more specific and allowed us to assess the contamination produced per firing, while the characterisation of military bases gives the magnitude of the contamination per range.

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Sommaire

Le contexte international de la démilitarisation, la fermeture de bases militaires, comme le "Massachusetts Military Reservation (MMR)", et la sévérité croissante des lois environnementales a entraîné à l'émergence de nouveaux champs de R&D dans le domaine de la défense. Plusieurs activités des Forces canadiennes telles que l'entraînement au tir de diverses munitions et la destruction de munitions désuètes ou en surplus par brûlage ou détonation extérieure peuvent provoquer la dispersion dans l'environnement de composés tels que les matériaux énergétiques et les métaux. Dans ce contexte, Recherche et développement pour la défense Canada (RDDC) -Valcartier en collaboration avec «Cold Regions Research and Engineering Laboratory» (CRREL), «US Army Engineer Research and Development Center (ERDC)» et «ERDC Environmental Laboratory (EL)», ont entrepris des programmes de recherches afin d'étudier les impacts environnementaux des composés énergétiques associés aux activités du ministère de la Défense nationale (MDN) et du Department of Defence (DoD). Les programmes de caractérisation de sites ont permis de développer une expertise unique et ont aidé nos organisations de défense à mieux comprendre les impacts des entraînements de tir réel et à se préparer à répondre à toute éventualité nécessitant des mesures correctives. Les premiers sites d'entraînement étudiés dans le cadre du program canadien financé par le Directeur Environnement de la force terrestre (DEFT) ainsi que par un programme majeur de fonds américains, le «Strategic Environmental R&D Programme (SERDP)» étaient situés sur les bases de Chilliwack, Shilo, Valcartier et Gagetown. Récemment, les efforts ont été concentrés sur les positions de tir. Des échantillons de sol et de biomasse ont été prélevés aux positions de tir et les résultats ont montré des quantités significatives de 2,4-dinitrotoluène (DNT) et de nitroglycérine (NG), composés appartenant aux poudres propulsives utilisées sur le marché.

Ce rapport décrit l'étude des résidus de tirs émis à la bouche de deux types d'armes, les obusiers LG1 Mark II et C3 105-mm, étude réalisée lors d'un exercice d'artillerie qui a eu lieu du 9 au 12 mai 2005 à la BFC Gagetown au Nouveau-Brunswick. Des plaques témoins en aluminium ont été placées sur le sol à la bouche du canon et les résidus de tirs ont été recueillis en nettoyant les plaques d'aluminium à l'aide de compresses en coton imbibées d'acétone. Pour approfondir l'étude, des échantillons de sol ont également été prélevés avant et après les tirs devant la bouche du canon. Les échantillons de sol pris avant les tirs permettent d'identifier les contaminants et leur concentration avant que l'exercice militaire ne débute. Les matériaux énergétiques dans les sols et les compresses de coton ont été caractérisés à RDDC Valcartier par chromatographie liquide à haute performance (CLHP), tandis que les métaux ont été caractérisés uniquement dans les sols par spectrométrie de masse couplée à un plasma inductif (SM/CPI) par un laboratoire privé, Bodycote essais de matériaux à Montréal. À l'aide de cette étude, il sera possible d'évaluer l'influence de la quantité de poudres à canon utilisée pendant le tir, le type de canon ainsi que le nombre de tirs effectués par un canon spécifique sur la quantité de résidus récupérés à la bouche du canon. Finalement, ce travail permettra également de déterminer la contamination associée directement aux tirs de canon.

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Acknowledgements

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1. Introduction

Military training ranges in Canadian Forces Bases are essential to prepare our troops for potential wars and peace missions. On the other hand, the growing environmental awareness of the Department of National Defence (DND) and of the population in general mandates that our Department evaluate the impact of training on the environment. During the last 10 years, methods for measuring the contamination by munitions residues have been developed (Ref. 1). A protocol describing different methods of sampling and the analytical chemistry was recently updated in collaboration with the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and is now available under the auspices of the Technical Cooperation Program (TTCP) by the member nations (Canada, the U.S.A., the U.K., Australia, and New Zealand) in a key technical area (KTA 4-28) (Ref. 2). Testing and training ranges are key elements in maintaining the capability, readiness, and interoperability of the Armed Forces. On military training ranges, munitions-related constituents can be released into the environment from breaches in the casings of unexploded ordnance (UXO) or partially exploded ordnance (low-order detonations), from poor disposal practices, such as unconfined burning operations; from blow-in-place operations; and from live-fire operations. Many papers have been written in recent years concerning the characterisation, analysis, fate, and transport of munitions-related residues in various types of sites (Ref. 1,3-25).

Recently, awareness has increased regarding the fact that energetic residues and heavy metals associated with munitions can be released in the environment during training activities and over time potentially contaminate the groundwater. Moreover, requirements have emerged related to the identification, quantification, and elimination of energetic contaminants dispersed by munitions or present in explosive dumps, trials or destruction fields, firing areas, and production sites (Refs. 1-5, 8, 9, 11-14, 28, 34-41). Many Canadian Forces sites used as impact areas, training ranges, demolition and open burning/open detonation (OB/OD) ranges that were used to destroy out-of-specification materials were suspected of being contaminated with energetic constituents (Refs. 3, 4, 8, 9, 13, 14, 22, 28, 34, 35, 37, 41). Moreover, in the United-States, munitions training and testing exercises were suspended at the Massachusetts Military Reservation following the discovery of low concentrations of hexogen (RDX) in the groundwater beneath the main training area (Environmental Protection Agency (EPA) Order #2). The Strategic Environmental Research and Development Program (SERDP) funded several studies directed at the assessment of source terms, pathways of biodegradation, and fate of munitions residues on military training facilities. In Canada, the Director Land Environment (DLE), which is part of the Department of National Defence (DND), tasked Defence Research and Development Canada (DRDC) -Valcartier to perform a research program for the environmental characterisation of their main training areas.

Training range characterisation efforts focused on target areas where explosive residues were thought to be present. Recently, however, firing positions were found to be contaminated with propellant residues such as nitroglycerin (NG) and 2,4-dinitrotoluene (DNT). These constituents are embedded in nitrocellulose (NC) fibers that are deposited in front of, and around the guns (Refs. 26-29). NC is also a major ingredient in propellant formulations, but was not assayed because it is not considered toxic. A preliminary study was conducted in 2003 to evaluate the deposition of the gun residues from artillery gun firing at Canadian

Forces Base (CFB) Valcartier by placing aluminum witness plates at specified distances in front of the muzzle of the gun (Ref. 30). At CRREL, artillery activity residues were evaluated using snow cover to characterise the plume of deposition of the propellant residues (ref. 25, 31). Both studies demonstrated that the gun expels propellant residues during firings. Nitrocellulose fibers containing 2,4-DNT were collected and analyzed. In 2006, Walsh et al. studied the contamination of mortar firing positions (Ref. 32). NG was found at significant concentrations, especially with the 81-mm mortars rounds.

In May 2005, the Fifth Royal Canadian Horse Artillery from CFB Valcartier held a major artillery exercise at CFB Gagetown. Our team seized this opportunity to study the dispersion of particles from artillery firing activities and assess the energetic materials residues. The objective was to evaluate the quantity of residues expelled after firing with two different guns and to understand the effect of the internal ballistics by varying the propellant charges. The two guns, the LG1 Mark II and the C3 105-mm howitzers, are depicted in Figure 1. The residues collected at the firing positions came from the single base propellant M1, composed of 85% NC, 10% 2,4-DNT and 5 % dibutylphtalate. Other ingredients present at less than 1% are diphenylamine and potassium sulphate (Ref. 33).

In this trial, witness plates were used to collect gun propellant residues and to evaluate our sampling methods. The area covered by the plates was larger than the surface studied in 2003 (Ref. 30). Our objective was to evaluate the entire plume of contamination. Another objective was to measure the contamination of the soil in front of the muzzle of the guns by sampling the soil before and after the exercise. Into soil samples, energetic materials and metals were characterised. We also evaluated which gun, the LG1 Mark II or the C3, produces more residues. We also determined the influence that the number of bags of propellant had on the quantity of residues.

C3 105-mm howitzer

LG1 Mark II 105-mm howitzer

Figure 1. *Two types of guns used by Canadian Army*

2. Experimental Method

Estimates of the amount of residues deposited by static live-firing of the LG1 Mark II 105-mm howitzer and the C3 105-mm howitzer were made by analysing soil samples and samples collected from aluminium witness plates. The following section describes the sampling patterns and extraction and the analytical methods for soils and residues collected on aluminium plates.

2.1 Soil Sampling

2.1.1 Background Samples

Background soil samples were taken before the firings to estimate the concentration of energetic materials already present in the soil. Since the ranges were used in the past for training, differentiation of current and past residues would have been impossible without background samples. Therefore, before the guns were fired, soil samples were collected. Background samples were always built with 25-30 increments (sub-samples) of soil samples.

2.1.2 Soil Sampling Strategy

In past years the usual strategy for soil sampling consisted of sampling at firing positions, around a representative number of targets, and around suspected hot spots (broken casings, UXOs or debris, etc.). The whole characterisation of training areas in Gagetown was published in 2003 and 2004 (Ref. 15, 16, 26, 48).

In this study, only the firing positions were sampled. Multi-increment samples were taken in each single sub-area illustrated in Figure 2 (for example, seven multi-increment samples would be taken in the entire area presented in Figure 2). For Site 5, a square was added from 15 to 20 m. The area closest to the gun was divided into smaller sections because we thought more residue would be deposited in that area. Surface soils were collected to a depth of 5 cm.

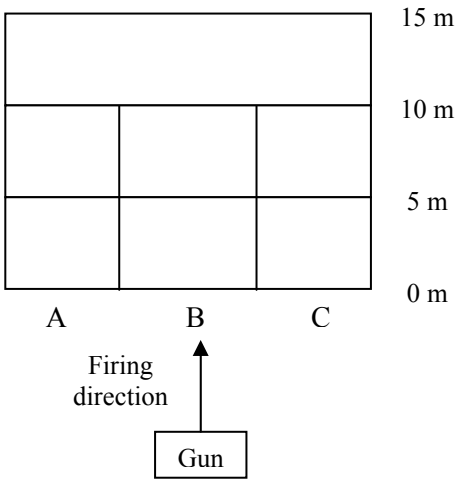

Figure 2. *Soil sampling areas relative to the gun position.*

Each soil sample was built with 25-30 increments. However, in some cases, we also collected multi-increments samples having 50 and 100 increments each. The 25- to 30-increment sampling is usually done in small surface (e.g., in a sub-square in Figure 2), while the 50- or 100-increment sampling is done in large areas, for example, the area covering the section from 15 m of the gun position and beyond (Fig. 2). In the following text, the soil samples will always refer to the 25- to 30-increment samples, while a mention will be made in the text when the number of increments was higher (50 or 100). One duplicate sample was collected for each site. All soil samples were stored in polyethylene bags.

2.1.3 Analytical Methods for Soils

Soil samples were analysed for metals and energetic materials. Metals were analysed, by an external laboratory (Bodycote Testing Group, Montreal, Quebec) using the method MA. 200, 1.1. approved by the Department of Environment of Quebec [43] involving a nitric acid/hydrogen peroxide digestion followed by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS). Metals analyzed for this study were silver (Ag), aluminium (Al), arsenic (As), boron (B), barium (Ba), beryllium (Be), Bismuth (Bi), calcium (Ca), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), rubidium (Rb), sulphur (S), selenium (Se), antimony (Sb), tin (Sn), strontium (Sr), tellurium (Te), titanium (Ti), thallium (Tl), uranium (U), vanadium (V), zinc (Zn), and zirconium (Zr). Samples were homogenized, as explained in

the following paragraph, and divided at DRDC Valcartier before sending one portion to Bodycote laboratory.

For energetic materials analyses, soil samples were air-dried in the dark and then homogenised by adding acetone until the soil was completely submerged to form a slurry. The acetone was then evaporated. Soils were sieved through 25-mesh sieve (< 710 μm) and extracted at DRDC Valcartier according to the following procedure. Eight grams of soil were put in an amber vial and mixed with acetonitrile (10 mL). Vortex was applied for one minute, followed by a sonification period of 18 h in an ultrasonic bath in the dark. The samples were left to settle for 30 min. Acetonitrile (2 mL) was removed from the vial and diluted with water (2 mL) containing calcium chloride (1%). The mixture was filtered on a 0.45-μm filter to get 1 mL of solution ready to inject into the high-pressure liquid chromatography (HPLC). Soil extracts were maintained at 4°C until analysed by HPLC according to method EPA 8330 (1994) (Ref. 42). The 14 compounds analysed for energetic materials were HMX, RDX, 1,3,5-TNB, 1,3-DNB, NB, TNT, tetryl, NG, 2,4-DNT, 2,6-DNT, 2-Am-DNT, 2-NT, 3-NT, and 4-NT.

The HPLC method was preferred to the gas chromatography (GC) method since reproducible results with the GC/ECD method were difficult to achieve and as concentrations expected were in the range of the mg/kg, analysis is easily achievable by the more rugged HPLC method (Ref. 11-12). In our study, the HPLC method reached a detection limit of 0.25 mg/kg for all analytes. Detection limits were reduced to 0.06 mg/kg when the extracts were concentrated (Turbovap evaporator, Zymark Corporation, Hopkinton, Massachussetts, USA). In order to obtain lower limits of detection, 2 mL of acetonitrile from the soil extract were evaporated to dryness with a Zymark evaporator in a test tube. Thereafter, 0.5 mL of water and 0.5 mL of acetonitrile were added; this mixture was used directly for the analysis. Analyses were performed with a HPLC Agilent HP 1100 equipped with a degasser G1322A, a quaternary pump model G1311A, an autosampler G1313A and an UV diode array detector model G1315A monitoring at 210, 220, and 254 nm. The injection volume was 20 μL and the column used was a Supelcosil LC-8 column 25 cm x 3 mm x 5 μm eluted with 15:85 isopropanol:water (V:V) at a flow rate of 0.75 mL/min. The column temperature was maintained at 25º C during the analysis. Standards and solvents were diluted 1:2, acetonitrile to water (0.5 mL ACN: 0.5 mL water).

2.2 Sampling of Residues on Plates

Plates placed downrange of the gun barrel were set out to collect the solid particles that were thrown from the muzzle of the gun. The dimensions of the plates were 1 m x 1 m and they were slightly concave, i.e. having a small hollow in the middle of the plate to catch water or solvent during sample recovery and cleaning. The plates were never used before this trial.

2.2.1 Sampling Strategy

The number of plates placed in front of the gun was determined by the topography of the site. Sometimes, no more than 10 plates could be accommodated and other times, as many as 27 plates were used. In each case, plates were placed to cover a maximum area in front of the gun. After firing, plates were cleaned with cotton wipes wetted with acetone to recover all the residues. The wipes were placed in amber glass jars. Each jar was dedicated to one plate.

2.2.2 Analytical Methods for Wipes

All bottles containing the cotton wipes were brought from the field to the laboratory without chemical or physical modification. Approximately 100 to 150 mL of acetonitrile were added in each bottle to cover the wipes. Bottles were placed on a shaker table for 18 hours and in a sonic bath for 1 hour. According to EPA method 8330 (Ref. 42), 7 mL of the extract was mixed with 7 mL of water for HPLC analysis. In some cases, the sample extracts were concentrated in a Zymark apparatus to reach lower detection limits.

3. Trials and Sampling Description

The military training exercises were performed between 9th and 12th of May 2005, at CFB Gagetown. A brief schedule of the exercise is given in Table 1. During the whole study, five sites were visited and sampled. The size of the area, the topography, and the possibility to sample the area in front of the gun were the criteria used to select the studied gun.

Table 1. *Schedule of the artillery exercises sites sampled at CFB Gagetown.*

	SITE 2	**SITE 3**	**SITE 4**	**SITE 5**	**SITE 6**
Day	Monday 9 May	Monday 9 May	Tuesday 10 May	Tuesday 10 May	Wednesday to Thursday 11-12 May
Hour	10:00 AM to 4:00 PM	10:00 AM to 4:00 PM	6:00 AM to 3:30 PM	6:00 AM to 3:30 PM	10:00 PM to 11:00 AM
Howitzer fired	LG1	C3	LG1	C3	LG1 and C3
Rounds fired	7 rounds at charge 4 and 7 rounds at charge 5	22 rounds at charge 4	13 rounds at charge 4	74 rounds at charge 5	34 rounds at charge 7 and 28 rounds at charge 7

The different kinds of 105-mm rounds fired were high explosives (HE), HE proximity, HE time, illuminating and HE plug C32. The difference between the HE rounds is the detection method to detonate the explosive at a fixed height. M1 single-base gun propellant, used in all tests, is composed of 85% NC, 10% 2,4-DNT (including 2,6-DNT as an impurity), and 5 % dibutylphtalate. Other ingredients present at less than 1% are diphenylamine and potassium sulphate (Ref. 33).

The total mass of propellant burned during the exercise was determined from the number of propellant bags used to propel the munitions. Table 1 gives the number of rounds with their charge and Table 2 gives the mass of propellant in each bag. The charge corresponds to the number of gun propellant bags used. For example, if bags 1, 2, 3 and 4 are used for the firing, the charge will be four. The maximum charge is seven. Then, when the charge is known, the complete mass of propellant used can be calculated. For example, a firing at charge 4 means that bags 1, 2, 3 and 4 were fired into the gun chamber, totaling a mass of 467 g of propellant. Moreover, bags 1 and 2 contain single-perforation grains, while bags 3 to 7 contain seven-perforation grains. The main difference between the single- and the seven-perforation is the surface area and, consequently, the rate burning; the single-perforation grain burns with a lower rate than a multiple-perforation grain.

Table 2. *Mass of propellant in bags 1 to 7 in 105-mm rounds.*

BAG	MASS OF PROPELLANT (g)
1	245
2	40
3	72
4	110
5	114
6	260
7	406

Note 1: Bag 5 contained a piece of lead foil 114 mm x 198 mm x 0.05 mm used as a decoppering agent (Ref. 44)

3.1 Area Airstrip 3

The first region visited by the military troops was Area Airstrip 3 located in Range 6 (green zone). Witness plates were placed at Sites 2, 3 and 4 and the GPS locations of these sites were reported in Table 10 in the annexes. The first trial was performed with 50 witness plates placed in front of an LG1 Mark II 105-mm howitzer and a C3 105-mm howitzer located in Sites 2 and 3, respectively (Fig. 3). These two guns were sampled at the same time (see Table 1). After this exercise, one part of the artillery moved to Site 4, another site at higher elevation than the other two sites (Fig. 4). The GPS locations of each plate at Sites 2 and 3 are presented in Tables 11 and 13 in the annexes (these data were not available at Site 4).

3.1.1 LG1 Mark II 105-mm Howitzer at Site 2, Area Airstrip 3

Figure 7 shows the locations of the 25 witness plates placed in front of the muzzle of the gun. Two plates were placed on each side of the muzzle of the

a)

b)

Figure 3. *Sites 2 (a) and 3 (b) located in Area Airstrip 3 in CFB Gagetown.*

gun at a distance of 5 m. A total of 27 plates were used. The 14 rounds fired with this gun were HE (five rounds), HE proximity (seven rounds) and smoke (two rounds). Seven rounds were fired at charge 4 and the seven other rounds at charge 5. The ground was soft, and consequently, soil sampling was conducted in this area. The four soil backgrounds were collected Sunday, a day before the exercise started. Since the locations of guns were unknown at that moment, the sampling was done on the complete surface area and not directly in front of the studied gun, as was the case for the other sites. Twelve samples including one duplicate were collected in front of the gun and two samples of 50 increments each were taken around the muzzle of the gun.

3.1.2 C3 105-mm Howitzer at Site 3, Area Airstrip 3

Figure 8 describes the location of the 23 witness plates placed in front of the gun, with a distance between the plates of 5 m, covering an area of approximately 25 x 30 m. The gun fired 22 rounds at charge 4, but the type of munitions fired was unknown. The composition of the ground was very similar to Site 2, i.e. sandy, making soil sampling easy. Eleven composite samples, including one duplicate, were collected in front of the gun and four soil samples of 100 increments each were taken in the complete firing zone.

3.1.3 LG1 Mark II 105-mm Howitzer at Site 4, Area Airstrip 3

The topography of that site was very different from the other three. In fact, the surface in front of the guns was covered by 60 cm-tall grass with some surface water that made the positioning of the witness plates and the sampling difficult. For this reason, no soil sampling was done at this site. Twenty-three aluminum plates were placed in front of the LG1 Mark II 105-mm howitzer (Fig. 4 and 9). Finally, 13 rounds of 105-mm at charge 4 were fired.

Figure 4. *Site 4 located in Area Airstrip 3 in CFB Gagetown.*

3.2 C3 105-mm Howitzer at Site 5

Site 5 (Fig. 5) was located in the Red Impact Area in the Dingee Wood Range, approximately 1 km south of the Area Airstrip 3. Twenty-seven aluminum plates were placed in front of the C3 105-mm howitzer as described in Figure 10. Seventy-four rounds of 105-mm at charge 5 were fired. Soil sampling was also conducted at Site 5. Twelve composite samples, including one duplicate, were collected in front of the gun, while two soil samples of 50 increments each were taken around the gun position. The GPS locations of each plate at Site 5 are grouped in Table 16 in the annexes.

Figure 5. *Site 5 located in the Dingee Wood Range in CFB Gagetown.*

3.3 Hersey Impact Area

For the two last days, the entire artillery troop was moved to the north entrance of the Hersey Impact Area, Site 6 in this study (Fig. 6). Two guns, one LG1 Mark II 105-mm howitzer and one C3 105-mm howitzer, were chosen for our study and the details of each sampled site are described in the following paragraphs. The topography of the site was different from other sites because at approximately 15 m in front of the gun, beyond a sand butte, a steep vertical drop was followed by a plain, the Hersey impact area. Soil samples were collected both before and after the guns were fired. The GPS locations of each plate placed in front of the LG1 Mark II and C3 105-mm guns at Site 6 are grouped in Table 18 in the annexes.

3.3.1 LG1 Mark II 105-mm Howitzer at Site 6

Ten witness plates were placed in front of the muzzle of the gun. Figure 11 a describes the pattern adopted to place them in front of the gun. Twenty-eight rounds were fired at charge 7 and the detail of the munitions is the following: 11 HE, 12 HE proximity, two HE time, and three illuminating. One background sample (the delay before they started firings had limited the number of backgrounds) and four multi-increment samples were taken at the firing position before and after the exercise, respectively.

3.3.2 C3 105-mm Howitzer at Site 6

Eight aluminum plates were placed in front of the muzzle of the gun. Figure 11 b describes the pattern adopted to place them in front of the gun. In that case, 34 rounds were fired at charge 7 and the details of the munitions used are as follows: 15 HE and 19 HE plug C32. Moreover, three soil background samples and three multi-increment samples were collected in front of the gun.

a. Entire area.

b. Witness plates in front of the gun.

Figure 6. *Site 6.*

4. Results

This section presents results from the sampling with witness plates and from the soil sampling. The advantage of using the plates is that the collected contamination comes from the current firing, while the soil may have been contaminated by previous firing exercises. The soil sample results were considered as complementary data. All results are placed in the annexes. However, the majority of the results are presented in summary tables in the text to make easier their comprehension and interpretation.

Residue data from the witness plates were used to estimate the mass of residues deposited by firing activities. The total mass of propellant burned during the exercise was determined from the number of propellant bags used to propel the munitions. The mass of residues deposited relative to the mass of propellant in each bag (see Table 2) was used to calculate the percentage of propellant residues deposited into the environment by the firing of these munitions. The mass is underestimated, because not all of the residue was collected by the plates and the total affected area was difficult to evaluate.

Soil sampling was performed to compare the results from soil accumulation versus plate deposition of the propellant residues produced after a live firing. Results only estimate the masses of residues since the soil residue concentrations were heterogeneous. Soil samples were collected at Sites 2, 3, 5 and 6. Soil sampling was not done at Site 4 because of the vegetation cover.

The characterisation of metals was performed on soil samples only. Results were compared with the Canadian Council of Ministers of the Environment (CCME) threshold. The analyses were done for several metals, but lead is the element of concern. In fact, the bag number 5 contained a piece of lead foil and this metal can be expelled in the environment by firings. The results showed that values were always lower than the CCME criteria. In the following sections, the metal characterisation will not be discussed again.

4.1 Sampling at Sites 2, 3, and 4 at Area Airstrip 3

4.1.1 LG1 Mark II 105-mm Howitzer at Site 2

Figure 7 shows the residues distribution at Site 2. Masses of 2,4-DNT and 2,6-DNT (in parentheses) are presented. Significant quantities of 2,4-DNT on each side of the gun were measured and the contamination was concentrated in front of the gun. The concentration of residues was higher on the left side of the gun when looking in the firing direction from the gun position, probably as a result of wind direction. Finally, the results obtained for the plates located at the extremities of the sampling area indicated that the area covered by the plates was not large enough to catch the entire plume since detectable levels of DNT were still present on the plates furthest from the gun.

Fourteen rounds at charges 4 and 5 (seven rounds of each) were fired, representing 467 and 581 g of propellant, respectively, for each shot. To obtain this value, for a charge 4, for example, one can sum the mass in bags 1 through 4 (Table 2). We calculated that 7336 g of propellant was burned during this exercise. Since 10 % of the propellant is 2,4-DNT, up to 733.6 g of 2,4-DNT were present in the gun propellant. 2,6-DNT is an impurity in the production of 2,4-DNT and represents 5% of the total mass of DNT collected. Ninety-one percent of the DNT was collected in the first three rows. The total quantity of DNT, including the 2,6-DNT, was used for the calculation. A mass of 12.94 mg was collected on the 27 aluminum plates that covered a surface of approximately 25 by 30 m, i.e., 750 m^2. The mass collected for 27 m^2 (27 plates of 1 m^2 each) was 12.94 mg; therefore 360 mg of residues was dispersed over the total area. It was assumed that the distribution of residues is the same over the unsampled area. This result means that 0.05 % of the total mass of fired DNT was deposited on the soil in front of the gun.

Ten of the 27 plates showed very low concentrations of RDX (maximum of 0.1 mg/m^2 and minimum of 0.0005 mg/m^2). These results are not included in Figure 7 because the contamination did not come from the current activity but probably from soil particles contaminated by past firing activities projected on the plates by the wind or the blast created by the gun.

	0,23 (0.01)	**Gun**	**0,96 (0.04)**		Row 0
0,04 (n.d.)	**0,18 (0.01)**	**2,83 (0.1)**	**2,48 (0.1)**	**0,09 (0)**	Row 1
0,07 (n.d.)	**0,26 (0.01)**	**0,17 (0.01)**	**3,26 (0.1)**	**0,06 (n.d.)**	Row 2
0,06 (n.d.)	**0,15 (0.01)**	**0,21 (0.01)**	**0,14 (0.01)**	**0,10 (n.d.)**	Row 3
0,06 (n.d.)	**0,13 (0.01)**	**0,09 (0)**	**0,21 (0.01)**	**0,27 (0.01)**	Row 4
0,04 (n.d.)	**0,06 (n.d.)**	**0,05 (n.d.)**	**0,05 (n.d.)**	**0,17 (0.01)**	Row 5

Figure 7. *Mass (mg) of 2,4-DNT and 2,6-DNT (in parentheses) collected on the witness plates at Site 2 (n.d. = not detected).*

Table 3 shows the soil concentrations at Site 2. A day before the trial, four background composite samples (Site2-sample 1, 2, 3 and 4) were taken in the whole area and a mean concentration of 2,4-DNT of 3.5 mg/kg was obtained. This result was significantly lower than the quantities of 2,4-DNT found between 0 and 5 m from the muzzle of the gun, with an average concentration of 43 mg/kg. The two samples collected at the gun position (2-1-GP) were grouped with the region between 0 and 5 m. Region C located on the left side of the gun, contained less contamination than regions A and B; this is in accordance with the trend observed with the aluminum plates (see Fig. 2). The mean concentration of 2,4-DNT observed between 5 and 10 m was 20 mg/kg, which is 50% less than the contamination found in the first region (0-5 m). The two other sections, between 10 and 15 m and 15 and 20 m, showed lower concentrations of 2,4-DNT, with 6 and 4 mg/kg, respectively. Finally, the three composites of 50 increments, named 2-1-20-X m-1, 2, and 3 collected at 20 m and farthest from the gun (X means that the end distance is unknown), showed significant concentrations of 2,4-DNT with an average value of 10.7 mg/kg.

2,6-DNT was detected for the five highest concentrations of 2,4-DNT only. The percentages of 2,6-DNT relative to the total mass of DNT were between 4 and 5.6 %, similar to the percentages observed in residues collected on the witness plates.

4.1.2 C3 105-mm Howitzer at Site 3

Figure 8 shows slightly higher contamination on the right side of the gun when looking in the firing direction from the gun position, but most of the 2,4-DNT was dispersed directly in front of the muzzle of the gun. As for Site 2, the results obtained for the plates located at the extremities of the rows indicated that the area covered by the plates was not large enough because detectable levels of 2,4-DNT were found on those plates.

Twenty-two rounds at charge 4 were fired, representing 10274 g of propellant, of which 10 % was 2,4-DNT (1027.4 g). Masses of 51.5 mg and 2.56 mg of 2,4- and 2,6-DNT, respectively, were collected on the whole surface, i.e., on the 23 aluminum plates covering an area of approximately 25 by 30 m (750 m^2). The 2,6-DNT represents 4.7 % of the total mass of 2,4- and 2,6-DNT collected. Eighty-six percent of 2,4-DNT was observed in the first three rows. As previously, the total mass of DNT was used in the calculation. Since 54.06 mg of DNT was found on a 23 m^2 area, by extrapolation, 1762.8 mg of DNT should occur for the whole surface of 750 m^2. This result means that 0.2 % of the initial DNT charge was deposited into the environment in front of the gun. At Site 3, only one plate showed soil contamination by RDX with a concentration of 0.002 mg/m^2.

Results obtained for the soil sampling done in front of the gun C3 105-mm howitzer at Site 3 are listed in Table 4. A concentration of 2,4-DNT of 1.06 mg/kg was obtained for the background sample taken before the firings (Site

Table 3. *Concentrations of RDX, TNT, 2,4-DNT, and 2,6-DNT in soil samples collected at Site 2.*

SAMPLE	RDX	TNT	2,4-DNT	2,6-DNT
	(mg/kg)	*(mg/kg)*	*(mg/kg)*	*(mg/kg)*
Background				
Site 2- sample 1	-	-	11.8	-
Site 2- sample 2	-	-	1.3	-
Site 2- sample 3	1.44	1.0	0.4	-
Site 2- sample 4	-	-	0.5	-
Mean value*	-	-	3.5	
After firing				
Site 2, GP-1	-	-	47.3	2.1
Site 2, GP-2	-	-	55.1	2.7
Site 2, 0-5 m A	-	-	53.3	3.2
Site 2, 0-5 m A DUP	-	-	34.5	1.4
Site 2, 0-5 m B	-	-	49.0	2.4
Site 2, 0-5 m C	-	-	19.7	-
Mean value*	-	-	43.2	2.3
Site 2, 5-10 m A	-	-	21.2	-
Site 2, 5-10 m B	2.6	-	28.8	-
Site 2, 5-10 m C	-	-	10.3	-
Mean value*	-	-	20.1	-
Site 2, 10-15 m	-	-	6.3	-
Site 2, 15-20 m	4.3	2.8	4.4	-
Site 2, 20-X m-1	-	-	2.6	-
Site 2, 20-X m-2	0.4	-	23.2	-
Site 2, 20-X m-3	-	-	6.3	-
Mean value*	-	-	10.7	-

* Mean value is not calculated when only one datum is available.

3-BG-1), while a mean concentration of 2,4-DNT of 16.92 mg/kg was detected between 0 and 5 m from the muzzle of the gun. The mean contamination of the first two regions, 0-5 m and 5-10 m, was not significantly different. In fact, 16.92 and 21.02 mg/kg were found for these two regions, respectively. The mean value calculated for the area from 10 m and farther dropped to 2 mg/kg. The results obtained for the sample «Site 3, 10-15 m» and its duplicate were significantly different, an indication that the soil contamination was not homogeneously distributed. Therefore, underestimation or overestimation of the contamination was easily possible.

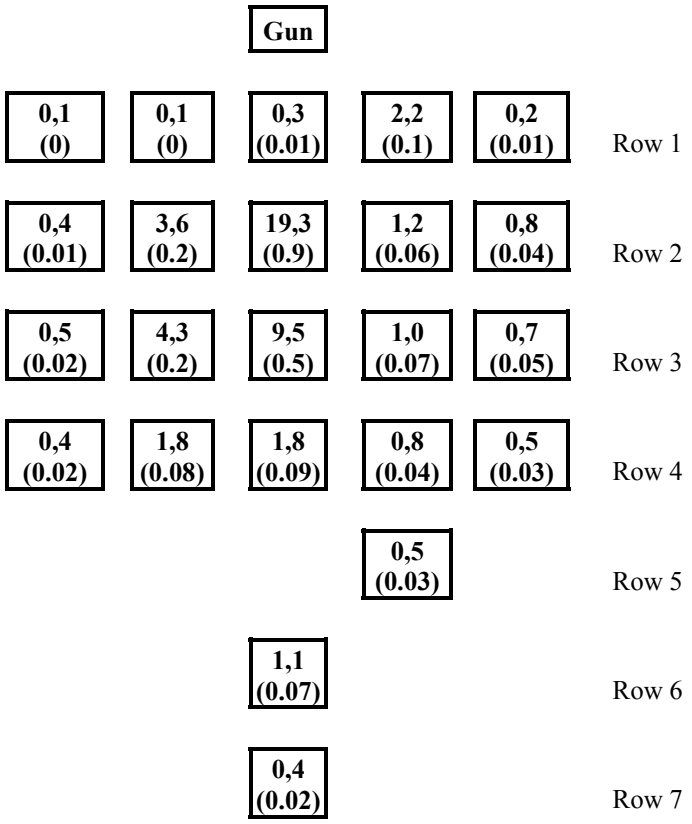

Figure 8. *Mass (mg) of 2,4-DNT and 2,6-DNT (in parentheses) collected on the witness plates at Site 3.*

The four samples of 100 increments named Site 3-A, B, C and D collected in the complete surface (40 m by 100 m) behind and in front of the gun showed very high concentrations of 2,4-DNT, which means that, after the exercise, this compound is present everywhere on the surface. In fact, the mean value obtained for the whole region was 41.18 mg/kg, higher than concentrations found directly in front of the gun.

In samples containing a concentration higher than 15 mg/kg of 2,4-DNT, 2,6-DNT was detected. The percentages of 2,6-DNT relative to the total mass of DNT were between 2 and 3 %. Finally, no RDX, TNT, HMX, nor 1,3,5-TNB were detected in soil samples.

Table 4. *Concentration of 2,4-DNT and 2,6-DNT in soil samples collected at Site 3.*

SAMPLE	2,4-DNT	2,6-DNT
	mg/kg	***mg/kg***
Site 3-BG-1	1.06	-
Site 3, 0-5 m A	10.75	-
Site 3, 0-5 m B	15.86	0.38
Site 3, 0-5 m C	24.14	0.65
Mean value	16.92	0.52
Site 3, 5-10 m A	61.82	1.05
Site 3, 5-10 m B	0.77	-
Site 3, 5-10 m C	0.49	-
Mean Value	21.01	1.05
Site 3, 10-15 m	1.90	-
Site 3, 10-15 m DUP	5.23	-
Site 3, 15-X m-1	1.35	-
Site 3, 15-X m-2	0.73	-
Site 3, 15-X m-3	0.99	-
Mean value	1.02	-
Site 3-A	40.02	0.97
Site 3-B	37.39	1.16
Site 3-C	58.05	1.99
Site 3-D	29.26	0.81
Mean value	41.18	1.23

4.1.3 LG1 Mark II 105-mm Howitzer at Site 4

Figure 9 describes the distribution of 2,4- and 2,6-DNT in front of the gun at Site 4 after the use of 6071 g of gun propellant for firings. The contamination was significantly higher on the left side of the gun when looking in the firing direction from the gun position and the wind direction is an explanation for this observation. No significant concentration of 2,4-DNT was found on the plates of rows 3, 4, 5, and 6. Thirteen rounds of 105-mm at charge 4 were fired utilizing 6071g of propellant, including 607.1 g of 2,4-DNT. The mass of 2,6-DNT represents 5.9 % of the total mass of DNT. However, 99 % of the 2,4-DNT was found between rows 1 to 3. In the 23 plates (23 m^2), 72.97 mg of DNT was collected and, consequently, by extrapolation, 1586.3 mg of DNT was found on the total area of 500 m^2 (25 x 20 m). This result means that 0.3 % of the DNT was expelled in front of the gun.

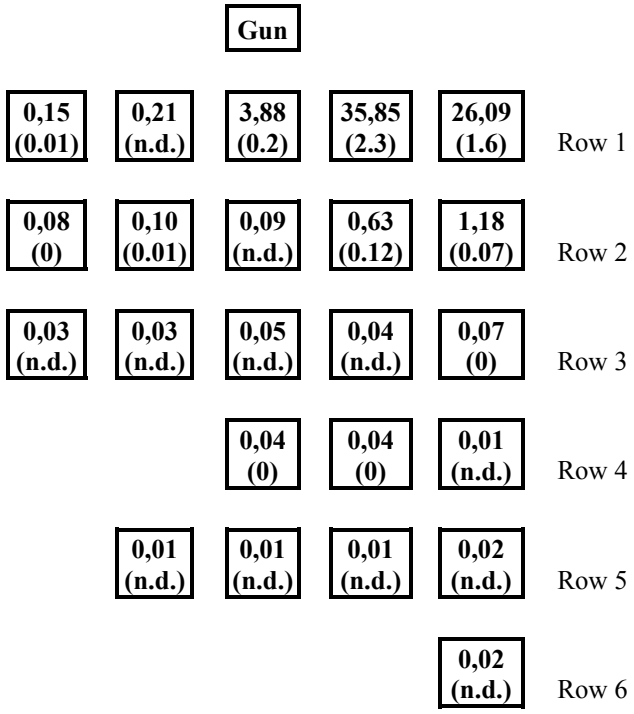

Figure 9. *Mass (mg) of 2,4-DNT and 2,6-DNT (in parentheses) collected on the witness plates at Site 4.*

Soil contamination was observed. In fact, HMX and 1,3,5-TNB were found once with a value 0.0003 and 0.002 mg/m^2, respectively, while RDX and 1,3-DNB were detected in three and five samples, respectively, with concentrations as low as those for HMX and 1,3,5-TNB. TNT was also present in 11 samples with a maximum value of 0.017 mg/m^2. This

contamination results from past military activities and is most probably affecting the analysis through particles being projected onto the plates by the wind or the muzzle blast.

4.2 C3 105-mm Howitzer at Site 5

The concentrations of 2, 4-DNT and 2,6-DNT found in front of the gun can be observed in Figure 10. The distribution shows that contamination was significantly higher on the left side of the gun when looking in the firing direction from the gun position, as was the case for Site 4. Ninety-seven percent of 2,4-DNT was found in rows 1, 2 and 3. Consequently, low concentrations of 2,4-DNT were found on the plates of rows 4, 5, 6 and 7. That shows that the plates were located far enough from the gun to establish most of the contamination plume. However, the results obtained for the plates located on the left side of the zone definitively show that it would be necessary to place more plates in this region. Significant quantities of 2,4-DNT would probably be found on plates on the left side, i.e. the contamination exceeded the studied area.

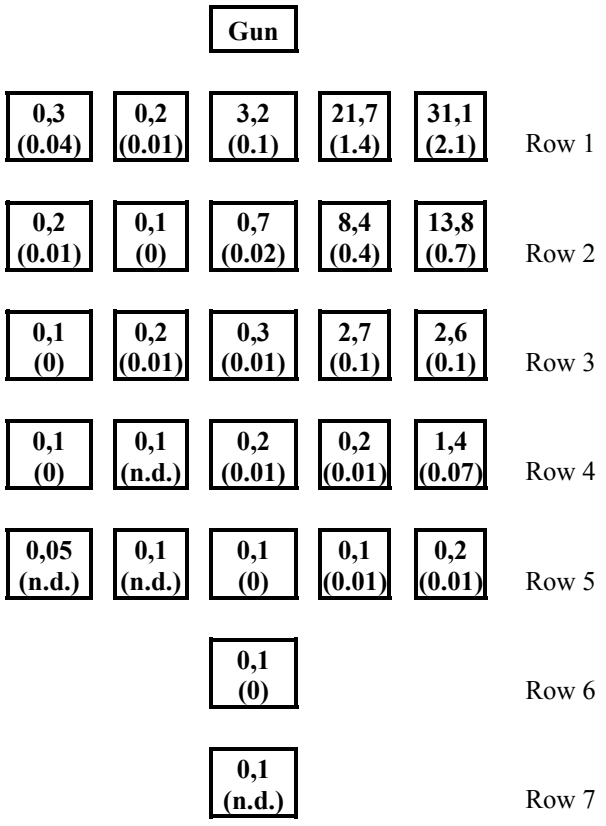

Figure 10. *Mass (mg) of 2,4-DNT and 2,6-DNT (in parentheses) collected on the witness plates at Site 5 (n.d. = not detected).*

The most intense firing was conducted at Site 5. Seventy-four rounds at charge 5 were fired for a total mass of propellant of 42.994 kg, including 4299.4 g of DNT. The total mass of 2,6-DNT represents 5.5 % of the collected DNT. A mass of 93.49 mg of DNT was measured on a surface area of 27 m^2, corresponding to the 27 plates. For the entire surface area of 625 m^2, 2164.12 mg was obtained by extrapolation. This result means that 0.05 % of the total mass of DNT was dispersed into the environment in front of the gun. Since the access to the site during the exercise was not permitted, sampling took place only at the completion of the exercise. Considering the long time period between the first fired rounds and the sampling, it is possible that particles were lost by displacement due to wind or blast from firings. Even if the wind can also bring particles on the plates, it is considered that the loss was more important than the accumulation.

Soil contamination was also found on eight plates at Site 5. Two plates showed concentrations of 1,3,5-TNB with a maximum concentration of 0.03 mg/m^2, RDX was present in five plates with a maximum of 0.002 mg/m^2, and TNT was found in four plates with a maximum of 0.63 mg/m^2.

Table 5. *Concentration of 2,4-DNT soil samples collected at Site 5.*

SAMPLE	2,4-DNT
	mg/kg
Site 5, GP-1	0.40
Site 5, GP-2	0.62
Site 5, 0-5 m A	1.01
Site 5, 0-5 m B	-
Site 5, 0-5 m C	-
Site 5, 5-10 m A	1.07
Site 5, 5-10 m B	0.31
Site 5, 5-10 m B DUP	-
Site 5, 5-10 m C	-
Site 5, 10-15 m	-
Site 15-20 m	-
Site 5, 20-X-1	-
Site 5, 20-X-2	-
Site 5, 20-X-3	-

Results obtained for soil samples collected at Site 5 are listed in Table 5. The contamination by 2,4-DNT observed at this site was lower than for Sites 2 and 3. Even for samples between 0 and 5 m from the muzzle of the gun, only one soil sample showed 2,4-DNT with a concentration of 1.01 mg/kg compared to 10 mg/kg and higher for Site 3. Even if the contamination was low, the highest concentrations of 2,4-DNT were still detected in the area between 0 and 10 m from the muzzle and around the gun position.

No 2,6-DNT, RDX, TNT, and 1,3,5-TNB were detected. These results are not in agreement with the contamination found on the aluminum plates because eight plates showed concentrations of 1,3,5-TNB, RDX and TNT. For 2,6-DNT, the result is in accordance with the previous sections that showed that 2,6-DNT was detected only when concentration of 2,4-DNT were sufficiently high, i.e., higher than 15 mg/kg.

4.3 LG1 Mark II 105-mm and C3 105-mm Howitzers at Site 6

The two guns were selected from among the whole battery for their accessibility and feasibility to sample in front of the gun. During this last exercise, the weather was rainy and windy, causing a direct effect on the results. Even though the LG1 Mark II and the C3 fired 28 rounds at charge 7 (34.92 kg of propellant) and 34 rounds at charge 7 (42.40 kg of propellant), respectively, no contamination was detected on the plates (Fig. 11). The probability that the pattern adopted to place the plates was responsible for this result is low because the plates were close enough to the gun, covering a significant surface area, and they should have caught some contamination, as with previous patterns.

Soil contamination was found on four plates located in front of the LG1 Mark II 105-mm howitzer. A low concentration of HMX (0.001 mg/m^2) was detected on plate 5; plate 8 contains traces of TNT, RDX, and 1,3,5-TNB with concentrations of 0.173, 0.0003 and 0.001 mg/m^2, respectively, while HMX and TNT were found on plate number 9 with concentrations of 0.004 and 0.011 mg/m^2, respectively. Finally, traces of RDX, i.e., 0.0005 mg/m^2, were detected on one plate.

The results from soil sampling done in front of the LG1 Mark II and C3 105-mm howitzer are grouped in Table 6. In both cases, the area in front of the gun was too short to apply the pattern described at Figure 2. Therefore, soil samples were built with 50 increments each taken in the complete area in front of the gun. Results obtained for the backgrounds (BG) and the samples are similar. Consequently, the 2,4-DNT detected cannot be confirmed to originate from the current exercise. No 2,6-DNT, HMX, TNT, RDX, or 1,3,5-TNB were detected in these soil samples. These results are not in agreement with the contamination found on the aluminum plates since these compounds were found on four plates located in front of the LG1 Mark II 105-mm howitzer.

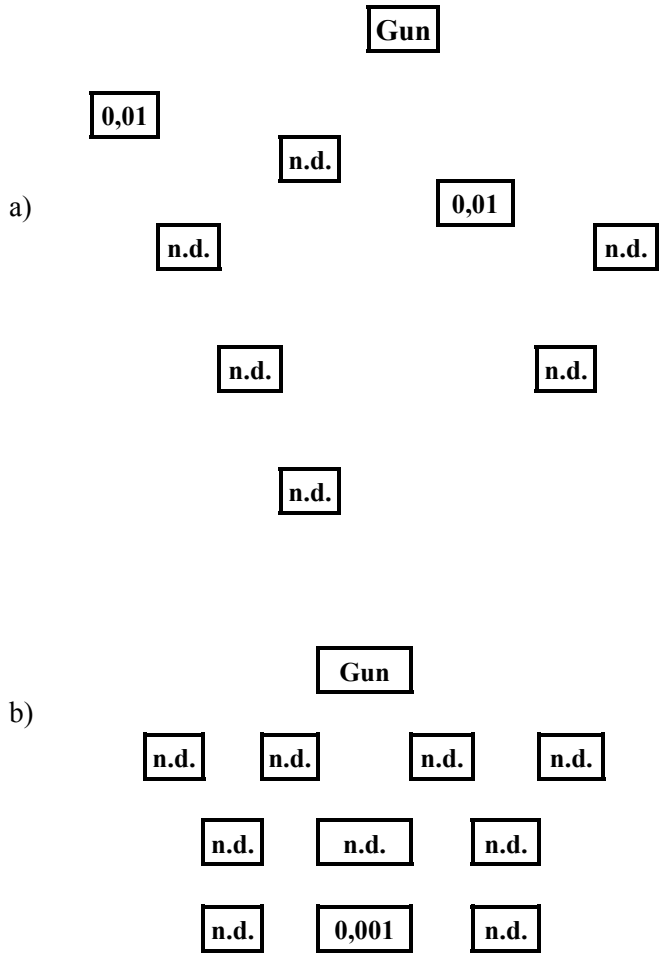

Figure 11. *Mass (mg) of 2,4-DNT collected on the witness plates at Site 6 a) LG1 Mark II 105-mm; b) C3 105-mm (n.d.=not detected).*
Note: No 2,6-DNT was detected at Site 6.

Table 6. *Concentration of 2,4-DNT in soil samples collected at Site 6.*

SAMPLE	2,4-DNT (mg/kg)
C3 105-mm	
Site 6-C3-BG 1	1.77
Site 6-C3-BG 2	0.44
Site 6-C3-BG 3	0.12
Site 6-C3-1	0.52
Site 6-C3-2	0.48
Site 6-C3-3	0.90
LG1 Mark II 105-mm	
Site 6-LG1-BG	1.07
Site 6-LG1-1	0.15
Site 6-LG1-2	0.23
Site 6-LG1-3	0.08

4.4 Summary

Table 7 presents the details of the results obtained from witness plates sampling at each site. Only M1 single-base propellant was used for the firings. Consequently, the main residue dispersed in front of the gun was 2,4-DNT. Table 7 clearly shows that the type of gun and the number of rounds did not influence the percentage of residue. However, the charge used, i.e., the quantity of propellant used for each firing, influenced the residue concentration. In fact, the larger the mass of gun propellant used for a firing, the lower the percentage of residue dispersed in front of the gun.

Table 8 presents the results obtained from soil sampling at Sites 2, 3, 5 and 6. For Site 5, only data for the first two layers (0-5 m and 5-10 m) are given because residues were not detected in the other surface areas. No residues were detected at Site 6, since background values were similar to the concentrations into soil samples. Table 8 mainly shows two trends: 1) at Sites 2 and 3, the 2,4-DNT was concentrated in the first 10 m from the gun position; 2) residues concentrations were lower at Sites 5 and 6 than at Sites 2 and 3. These two observations were also reported from the study with the witness plates.

Table 7. *Results obtained at each site from sampling with witness plates.*

TYPE OF 105-MM HOWITZER	NUMBER OF ROUNDS	CHARGE	PROPELLANT LOAD (g)	MASS OF DNT (g)	RESIDUE (mg)	SURFACE (m^2)	% RESIDUE
LG1 (Site 2)	14	4 and 5	7336	733.6	52.4	750	0.05
LG1 (Site 4)	13	4	6071	607.1	1586.3	500	0.3
LG1 (Site 6)	28	7	34920	3492	0.02	-	0
C3 (Site 3)	22	4	10274	1027.4	1762.8	750	0.2
C3 (Site 5)	74	5	42994	4299.4	2164.12	625	0.05
C3 (Site 6)	34	7	42400	4240	0.001	-	0

Table 8. *Concentration of 2,4-DNT and 2,6-DNT in soil samples collected at Sites 2, 3, and 5.*

SAMPLE	2,4-DNT	2,6-DNT
	mg/kg	***mg/kg***
Site 2, BG-1	3.5	-
Site 2, 0-5 m	43.15	2.33
Site 2, 5-10 m	20.1	-
Site 2, 10-15 m	6.3	-
Site 2, 15-20 m	4.4	-
Site 2, 20-X m	10.7	-
Site 3, BG-1	1.06	-
Site 3, 0-5 m	16.92	0.52
Site 3, 5-10 m	21.02	-
Site 3, 10-15 m	1.90	-
Site 3, 10-15 m DUP	5.23	-
Site 3, 15-X m	1.02	-
Site 5, 0-5 m	0.4	-
Site 5, 5-10 m A	0.5	-

5. Discussion

The trial performed at CFB Gagetown allowed the study of the dispersion of residues around and in front of guns after numerous firings. Residues from three LG1 Mark II 105-mm howitzers and three C3 105-mm howitzers firing positions were sampled using witness plates at Sites 2, 3, 4, 5 and 6. The two major contaminants were 2,4-DNT and 2,6-DNT. The 2,6-DNT, an impurity in the production of 2,4-DNT, was often detected on the witness plates and represented approximately 5 % of the total DNT.

The highest quantities of DNT were found in the first three rows in front and on each side of the gun. Therefore, most of the contamination is located just beside the gunners.

At Site 5, low concentrations of 2,4-DNT were observed, which was unexpected since the greatest amounts of propellant were fired there. However, at Site 5, even if the concentrations of 2,4-DNT were lower than expected, the contamination was concentrated in the first rows as observed for Site 2, 3 and 4. At Site 6, no contamination was detected on most of the plates. The weather at the end of the week was windy and rainy and this may explain these results. Soil contaminations by RDX, HMX, TNT and 1,3,5-TNB were observed on most of the plates.

In Table 9, the percentages of DNT deposited in front of the gun were grouped by site. The number of rounds fired with the charge is also given. From these results, the type of gun did not seem to affect the quantity of residues. In fact, the percentages of residues obtained from these guns were similar. Moreover, the number of rounds did not seem to influence the percentage of DNT found on the witness plates. In fact, at Site 5, the highest number of rounds was fired and the percentage of residues was low. However, the charge used for the firings seems to have an effect on the percentages recovered. In fact, the highest percentages were found at Sites 3 and 4, where the charge was the lowest (4 bags). The comparison of Site 2 with the results at other sites is difficult since charges 4 and 5 were both used. Finally, at Site 6, no contamination was detected. Site 6 was the only site where the maximum charge, i.e. 7 bags, was used for all firings.

In a preliminary study performed in 2003 at DRDC Valcartier by Dubé et al. (Ref. 30), the percentage of propellant recovered was on the same order of magnitude as those reported in this report. After 10 rounds at charge 4 with a LG1 Mark II 105-mm howitzer, they found 0.56 % of the total fired 2,4-DNT in front of the muzzle in an area of 42 m^2.

Table 9. *Calculated percentages of recovered DNT dispersed in front of the gun in each site.*

SITE	# ROUNDS WITH THE CHARGE	C3 105-MM HOWITZER	LG1 MARK II 105-MM HOWITZER
Site 2	7 rounds at charge 4 and 7 rounds at charge 5		0.05 %
Site 3	22 rounds at charge 4	0.2 %	
Site 4	13 rounds at charge 4		0.3 %
Site 5	74 rounds at charge 5	0.05 %	
Site 6	34 rounds at charge 7	0 %	
Site 6	28 rounds at charge 7		0 %

Walsh et al. (Ref. 31) studied the residues from live fire detonations of 155-mm howitzer rounds in 2005 on snow. From three 100-increment snow samples, they estimated that 110, 19 and 86 mg of 2,4-DNT were dispersed by the firing of 60 rounds over a surface area of 30 by 30 m (900 m^2). For each firing, 2.8 kg of single-base propellant was consumed, which indicated that full charge was always used. For Site 5, we estimated a dispersion of 3116 mg of DNT for an area of 900 m^2 after 74 rounds at charge 5, corresponding to 581 g of single-base propellant for each firing. Our results demonstrate that the contamination was significantly more important in our study. However, many factors could explain this difference: the weather (wind and rain), the type of soil, the vegetation, the charge used for the firing and the type of propellant. Furthermore, different guns were used and the quantity of propellant used per firing was higher with the 155-mm (2.8 kg) than for the 105-mm even at full charge (1.25 kg). Walsh et al. also found that the 2,4-DNT was more concentrated in the region between 0 and 10 m from the gun.

In the second part of the study, soils were characterised at Sites 2, 3, 5 and 6. At Sites 2 and 3, significant concentrations of 2,4-DNT were found and the concentrations were highest close to the gun. The highest concentration was detected at Site 3 between 5 and 10 m from the muzzle of the gun (61.82 mg/kg). At Sites 2 and 3, the effect of the firings on soil contamination was significant because 3.5 and 1 mg/kg of 2,4-DNT were detected, respectively, before the trial, while the average concentrations of 26 and 19 mg/kg were found, respectively, in soil samples after the firings in the region of 0 to 10 m from the gun. An additional observation was that 2,6-DNT was detected only when concentrations of 2,4-DNT in soil samples were higher than 15 mg/kg.

At Site 5, the concentrations of 2,4-DNT were lower than expected, but exhibited the same trend as observed for Sites 2, 3 and 4, i.e. the contamination was greater close to the gun. However, at Site 6, background samples and samples collected after the firings gave similar results. The weather, the morphology of the site and the type of soil may explain this last observation. As no tree nor grass were present at these sites, the wind may have been more efficient at dispersing the contamination compared with Sites 2, 3 and 4, where little trees and

long-grass covered the soil, which probably prevents the wind from blowing away the particles. Moreover, the type of soil was different at Sites 5 and 6 and that may affect the extraction method. In fact, the soil was sandy and the specific surface was higher than for dirt and, consequently, the interaction between organic matter and the analyzed compounds may increase with the contact surface. That may explain why low concentrations of 2,4-DNT and no 2,6-DNT, HMX, RDX, TNT and 1,3,5-TNB were found into soil samples collected at Site 5 and 6. Moreover, the low concentrations of DNT could be explained by the fact that at Sites 5 and 6, firings were performed at charges 5 and 7 and the residues could be less important because, at this charge, a more complete combustion existed.

Chemical compounds such as HMX, RDX, TNT and 1,3,5-TNB were often found on the aluminum plates, but not in the soil. The interaction between the soil and the chemical compounds could probably explain that the extraction of contaminant by acetonitrile may be less efficient from soil samples than from cotton wipes that do not contain other organic matter that can interact with the analytes. It is also important to mention that just a small quantity (4 or 8 g) of the soil was taken for the extraction and, consequently, if the distribution of the contamination was not homogeneous, no compound could be detected even if contamination was present into the soil. Adding acetone into the soil to make a slurry had demonstrated its efficiency, but residues embedded into NC fibers can be difficult to dissolve and, consequently, underestimate the mass of residues measured into soil samples. In fact, with the duplicate, it was often demonstrated that results obtained from the same region could be significantly different.

In 2001 Jenkins et al. (Ref. 17) studied soil contamination in front of two 105-mm howitzers that fired 600-rounds each during six weeks. The size of the sampled areas in front of the two guns was 80 m^2 and 320 m^2, respectively, and the contamination of 2,4-DNT was between 982 and 237 000 µg/kg (or 0.982 and 237 mg/kg). These results are in accordance with our values, even if the maximum concentration of 2,4-DNT found in their study was higher than the current data; the number of rounds fired in 2001 was significantly higher than the number fired in the current exercise.

Walsh et al. (Ref. 25) studied the residues dispersion provided by the firing of 100 rounds of 105-mm and they found that even at a distance of 50 m from the gun, 2,4-DNT was still detected and that the distribution was also heterogeneous. Finally, the sampling was done in a sparsely vegetated gun position and in a vegetated gun position. The 2,4-DNT was found in the subsurface only at the sparsely vegetated gun position. The conclusion was that «the organic matter in the vegetated soil would be expected to sorb any 2,4-DNT that dissolves in the surface moisture».

6. Conclusions

The highest residue concentrations were observed at Sites 3 and 4 with percentages of 0.2 and 0.3 %, respectively, of DNT relative to the total amount of DNT fired during the exercise. A lot of factors influenced the amount of residues collected. In fact, it was often noted with the results on plates that the wind affected the residues distribution on the surface. From the soil sampling, interesting results were also obtained for Sites 2 and 3; concentrations up to 61.8 mg/kg where obtained in the first 10 m in front of the gun. With plates, it was also observed that the contamination was concentrated directly in front of the muzzle.

For Sites 5 and 6, the measured concentrations were lower than expected. The weather conditions, the method of extraction (cotton wipes versus soil medium) and the number of charges consumed for the firings could explain this last observation. However, the number of bags of gun propellant used for firings was larger at these sites. Therefore, the combustion of the propellant may be more efficient when the mass of the propellant is larger. Consequently, the residues concentrations were lower than for firings with a lower quantity of propellant. In addition, when results were compared for the two types of guns, it was not possible to determine which gun was the most environmentally-friendly because the results of these two types of guns were similar.

Comparison of witness plates and soil results was difficult since the distribution of residues in the soil was heterogeneous and the plates were subject to residue loss and redistribution by the wind. A future trial should be conducted in a closed vessel to allow all the particles to be caught during the firing. In future work, the sampled area should be expanded in order to reach the boundary of the plume and obtain a more reliable estimation of the dispersed DNT.

The particles expelled by the muzzle of the gun are in significant amounts near the gun. Furthermore, the products expelled may be dangerous for the health of the gunners, since they might be directly exposed to the contamination plume. No analysis was made directly for the gunner's health. The gunner's proximity to the highest residues concentrations found during our tests indicates that further studies of the health risks associated with this situation are warranted.

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Annexes

Table A1. *GPS positions of Sites 1, 2, 3 and 4 located in the Area Airstrip 3.*

GPS POSITIONS			
Site 1	***Site 2***	***Site 3***	***Site 4***
0716159-5073500	0716397-5073340	0716593-5073256	0715688-5073594
0716100-5073529	0716347-5073311	0716607-5073280	0715669-5073600
0716065-5073549	0716346-5073333	0716746-5073176	0715673-5073615
0716007-5073599	0716336-5073395	0716736-5073151	0715690-5073603

Table A2. *GPS positions of aluminium plates at Site 2.*

PLATE NUMBERS	GPS POSITIONS
2-0-A	0716426-5073360
2-1-A	0716426-5073358
2-2-A	0716420-5073352
2-3-A	0716416-5073346
2-4-A	0716410-5073343
2-5-A	0716407-5073338
2-0-E	0716414-5073369
2-1-E	0716402-5073356
2-2-E	0716400-5073355
2-3-E	0716396-5073347
2-4-E	0716369-5073349
2-5-E	0716392-5073346

Table A3. *Concentration of 2,4- and 2,6-DNT collected on the aluminium plates at Site 2.*

PLATE	2,4-DNT	2,6-DNT
	mg/m^2	mg/m^2
2.0 a	0.96	0.041
2.0 b	0.23	0.009
2.1 a	0.09	0.003
2.1 b	2.48	0.105
2.1 c	2.83	0.134
2.1 d	0.18	0.007
2.1 e	0.04	-
2.2 a	0.06	-
2.2 b	3.26	0.142
2.2 c	0.17	0.006
2.2 d	0.26	0.010
2.2 e	0.07	-
2.3 a	0.10	-
2.3 b	0.14	0.006
2.3 c	0.21	0.009
2.3 d	0.15	0.006
2.3 e	0.06	-
2.4 a	0.27	0.012
2.4 b	0.21	0.008
2.4 c	0.09	0.004
2.4 d	0.13	0.006
2.4 e	0.06	-

Table A4. *Concentration of 2,4- and 2,6-DNT collected on the aluminium plates at Site 2 (continued).*

PLATE	2,4-DNT	2,6-DNT
	mg/m^2	mg/m^2
2.5 a	0.17	0.007
2.5 b	0.05	-
2.5 c	0.05	-
2.5 d	0.06	-
2.5 e	0.04	-

Table A5. *GPS positions of aluminium plates at Site 3.*

PLATE NUMBERS	GPS POSITIONS
3-1-A	0716711-5073162
3-2-A	0716711-5073158
3-3-A	0716707-5073155
3-4-A	0716705-5073150
3-5-A	0716698-5073151
3-6-A	0716691-5073151
3-7-A	0716689-5073149
3-1-E	0716695-5073177
3-2-E	0716696-5073167
3-3-E	0716692-5073164
3-4-E	0716692-5073163

Table A6. *Concentration of 2,4- and 2,6-DNT collected on the aluminium plates at Site 3.*

PLATE	2,4-DNT	2,6-DNT
	mg/m^2	mg/m^2
3.1 a	0.2	0.01
3.1 b	2.2	0.10
3.1 c	0.3	0.01
3.1 d	0.1	0.004
3.1 e	0.1	0.003
3.2 a	0.8	0.04
3.2 b	1.2	0.06
3.2 c	19.3	0.90
3.2 d	3.6	0.24
3.2 e	0.4	0.01
3.3 a	0.7	0.05
3.3 b	1.0	0.07
3.3 c	9.5	0.46
3.3 d	4.3	0.20
3.3 e	0.5	0.02
3.4 a	0.5	0.03
3.4 b	0.8	0.04
3.4 c	1.8	0.09
3.4 d	1.8	0.08
3.4 e	0.4	0.02
3.5 a	0.5	0.03
3.6 a	1.1	0.07
3.7 a	0.4	0.02

Table A7. *Concentration of 2,4- and 2,6-DNT collected on the aluminium plates at Site 4.*

PLATE	2,4-DNT	2,6-DNT
	mg/m^2	mg/m^2
4.1 a	26.09	1.6
4.1 b	35.85	2.313
4.1 c	3.88	0.207
4.1 d	0.21	-
4.1 e	0.15	0.005
4.2 a	1.18	0.066
4.2 b	0.63	0.124
4.2 c	0.09	-
4.2 d	0.10	0.006
4.2 e	0.08	0.003
4.3 a	0.07	0.003
4.3 b	0.04	-
4.3 c	0.05	-
4.3 d	0.03	-
4.3 e	0.03	-
4.4 a	0.01	-
4.4 b	0.04	0.001
4.4 c	0.04	0.001
4.5 a	0.02	-
4.5 b	0.01	-
4.5 c	0.01	-
4.5 d	0.01	-
4.6 a	0.02	-

Table A8. *GPS positions of Site 5.*

GPS POSITIONS
0716098-5071599
0716091-5071586
0716117-5071590
0716106-5071579

Table A9. *Concentration of 2,4- and 2,6-DNT collected on the aluminium plates at Site 5.*

PLATE	2,4-DNT	2,6-DNT
	mg/m^2	mg/m^2
5.1 a	31.1	2.068
5.1 b	21.7	1.352
5.1 c	3.2	0.144
5.1 d	0.2	0.007
5.1 e	0.3	0.036
5.2 a	13.8	0.688
5.2 b	8.4	0.428
5.2 c	0.7	0.022
5.2 d	0.1	0.004
5.2 e	0.2	0.005
5.3 a	2.6	0.129
5.3 b	2.7	0.122
5.3 c	0.3	0.012
5.3 d	0.2	0.006
5.3 e	0.1	0.004
5.4 a	1.4	0.065
5.4 b	0.2	0.011

Table A10. *Concentration of 2,4- and 2,6-DNT collected on the aluminium plates at Site 5 (continued).*

PLATE	2,4-DNT	2,6-DNT
	mg/m^2	***mg/m^2***
5.4 c	0.2	0.008
5.4 d	0.1	-
5.4 e	0.1	0.004
5.5 a	0.2	0.009
5.5 b	0.1	0.006
5.5 c	0.1	0.003
5.5 d	0.1	-
5.5 e	0.05	-
5.6 a	0.1	0.003
5.7 a	0.1	-

Table A11. *GPS positions of aluminium plates at Site 6.*

LG1 MARK II 105-MM HOWITZER	
PLATES NUMBERS	**GPS POSITIONS**
6-LG1-1	0710602-5076778
6-LG1-2	0710603-5076775
6-LG1-3	0710605-5076773
6-LG1-4	0710606-5076768
6-LG1-5	0710601-5076768
6-LG1-6	0710599-5076772
6-LG1-7	0710597-5076776
6-LG1-8	0710794-5076776
6-LG1-9	0710595-5076772
6-LG1-10	0710596-5076767
C3 105-MM HOWITZER	
PLATES NUMBERS	**GPS POSITIONS**
6-C3-1	0710568-5077119
6-C3-2	0710570-5077112
6-C3-3	0710570-5077108
6-C3-4	0710570-5077104
6-C3-5	0710567-5077105
6-C3-6	0710563-5077104
6-C3-7	0710564-5077108
6-C3-8	0710566-5077112

List of symbols/abbreviations/acronyms/initialisms

ACN	Acetonitrile
BIP	Blown-in-place
CCME	Canadian Council of Ministers of the Environment
CFB/ASU	Canadian Forces Base/Area Support Unit
CFAD	Canadian Forces Ammunition Depot
CRREL	Cold Regions Research and Engineering Laboratory
DLE	Director Land Environment
DND	Department of National Defence
DNT	Dinitrotoluene
DoD	Department of Defence
DRDC	Defence Research and Development Canada
DUP	Duplicate
ECD	Electron capture detector
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
GC	Gas chromatography
GPS	Global positioning system
HE	High energy
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HPLC	High performance liquid chromatography
ICP/MS	Inductively coupled plasma/mass spectrometry

INRS-ETE	Institut National de la Recherche Scientifique Eau, Terre et Environnement
MDN	Ministère de la Défense Nationale
NC	Nitrocellulose
NG	Nitroglycerin
OB/OD	Open burning/open detonation
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
SERDP	Strategic Environmental R&D Program
SM/CPI	Spectrométrie de masse couplée à un plasma inductif
TNT	2,4,6-trinitrotoluene
TTCP	The Technical Cooperation Program
UV	Ultraviolet
UXO	Unexploded ordnances

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Military training on fields and ranges at Canadian Forces Bases (CFB) is essential to prepare our troops for potential wars and/or peace missions. On the other hand, the growing concern of DND leaders and of the general population makes it necessary to evaluate the impacts of training on the environment. During the last 10 years, new methods of characterization have been developed to assess the energetic materials contamination, which is different from the usual contamination in residential or industrial scenarios. Recently, the efforts were focused on firing positions. Soil and biomass sampled at firing positions have shown detectable levels of gun propellant residues, such as 2,4-dinitrotoluene (2,4-DNT) and nitroglycerine (NG). In this study, aluminium witness plates were placed in front of the muzzle of the gun to collect residues propelled in the environment. Cotton wipes were used to collect the residues on plates. Moreover, as complementary data, soil samples were taken before and after the military exercise using a composite approach to be statistically representative. The energetic materials were analyzed at DRDC Valcartier in Quebec City by high performance liquid chromatography (HPLC) and metal analyses were performed at Bodycote Testing Group in Montreal only for soil samples. This work was realized in May 2005 and was supported by the Sustain Thrust of DRDC and the Strategic Environmental Research and Development Program (SERDP), Washington D.C., USA.. (U)

L'entraînement militaire des Forces canadiennes est essentiel pour préparer les troupes aux guerres potentielles et/ou aux missions de paix. Par ailleurs, l'intérêt grandissant du MDN et de la population pour l'environnement rend nécessaire l'évaluation de l'impact de l'entraînement sur l'environnement. Au cours des 10 dernières années, de nouvelles méthodes de caractérisation on été développées pour évaluer la contamination en matériaux énergétiques qui est différente des scénarios résidentiel ou industriel habituels. Récemment, les efforts ont été concentrés sur les positions de tir. Des échantillons de sol et de biomasse prélevés aux positions de tir ont montré des quantités significatives de composés, tels que le 2,4-dinitrotoluène (DNT) et la nitroglycérine, appartenant aux compositions de poudres à canon. Dans cette étude, des plaques témoins en aluminium ont été placées en face de la bouche du canon pour récolter les résidus de tirs propulsés dans l'environnement. Les plaques ont été nettoyées à l'aide de compresses en coton afin de récupérer les résidus. De plus, des échantillons de sol ont été prélevés avant et après les exercices de tir comme données complémentaires selon une approche composite pour être statistiquement représentatifs. Les analyses des matériaux énergétiques ont été réalisées à RDDC Valcartier dans la ville de Québec, tandis que celles des métaux ont été effectuées chez Bodycote essais de matériaux à Montréal. Ce travail a été réalisé au mois de mai 2005 dans le cadre du vecteur "maintien en puissance" de RDDC et du programme américain de subvention «Strategic Environmental Research and Development Program (SERDP)», géré à Washington D.C., aux Etats-Unis. (U)

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